Screw Motion Used in Semiconstrained Rotational Plate Systems for Anterior Cervical Discectomy and Fusion

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Study Design: Retrospective observational study.

Objective: To scrutinize screw motion used in semiconstrained rotational plate systems for anterior cervical discectomy and fusion (ACDF).

Summary of Background Data: Semiconstrained rotational plate systems are supposed to control graft subsidence and facilitate lordosis acquisition and maintenance by toggling the instrumented vertebrae via variable-angle screws. However, their benefits may be unrealized if the screws move within the vertebrae.

Methods: We reviewed medical records of 119 patients who underwent 1-level, 2-level, 3-level, or 4-level ACDF, divided them into the short-segment (n = 62, 1-level or 2-level ACDF) and long-segment (n = 59, 3- level or 4-level ACDF) groups, and investigated their immediate and 1-year postoperative lateral radiographs. We measured the fused segmental angle, screw angles at the upper-instrumented vertebra (UIV) and lower-instrumented vertebra (LIV), distance from the screw base to the endplate of UIV/LIV (SBE), and distance from the screw tip to the endplate of UIV/LIV (STE) to analyze the screw motion used in these plate systems. The differences between the immediate and 1-year postoperative values were statistically analyzed. The nonunion level was also investigated.

Results: Screw angle and SBE at the LIV significantly decreased in the long-segment group (-14.5 ± 9.8 degrees and -2.8 ± 1.8 mm, respectively) compared with those in the short-segment group (-4.6 ± 6.0 degrees and -1.0 ± 1.5 mm, respectively). Thus, the long-segment group could not maintain the immediate-postoperative segmental angle. Overall, 27 patients developed nonunion, with 19 (70.4%) in the long-segment group and 21 (77.8%) at the lowest fused level.

Conclusions: Semiconstrained rotational plate systems provide only vertical forces to the fused segment rather than toggling the instrumented vertebrae. Postoperatively in multilevel ACDF, LIV screws migrate caudally, suggesting that these plate systems are not always effective in maintaining lordosis. Moreover, LIV screws and the anterior wall of the LIV are subject to overloading, resulting in a high rate of nonunion at the lowest fused level.

Level of Evidence: Level III.

Key Words: anterior cervical discectomy and fusion, semiconstrained, rotational, nonunion

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When performing anterior cervical discectomy and fusion (ACDF) with plating, 2 plate types are mainly commercially available. One is classified into semiconstrained translational plate systems—equipped with slotted holes in the plate or a combination of slotted holes and self-adjustable plate length with the choice of variable- or fixed-angle screws. The other has only circular holes in the plate. However, it can be a constrained or semiconstrained rotational type if all fixed-angle screws or variable-angle screws are used, respectively.[1,2]

Constrained plate systems risk stress shielding if the graft is not firmly in contact with the intervertebral space. In contrast, semiconstrained plate systems can distribute the load across the graft construct by allowing vertical or rotational motion of the fused level. In semiconstrained translational plate systems, intuitively, dynamization is crucial. However, they are more generous with graft subsidence, resulting in plate migration to adjacent intervertebral discs.[2,3] Conversely, semiconstrained rotational plate systems, which rely on the toggling of the instrumented vertebrae via variable-angle screws at the screw-plate interface, would ideally be superior in controlling graft subsidence, thus contributing to the acquisition and maintenance of lordosis.

However, the benefits of semiconstrained rotational plate systems are not completely realized if the screws move within the vertebrae. If this is the case, these plate systems may not effectively increase lordosis and transfer load to the interbody graft during the postoperative course because they cannot effectively toggle the instrumented vertebra at the screw-plate interface. This study is the first to scrutinize the screw motion, focusing on the positional relationship between the instrumented vertebrae and

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screws. We also examined the impact of these plate systems on alignment maintenance and bony fusion at the fused level.

METHODS

This retrospective observational study was conducted in accordance with the ethical principles specified in the 1964 Declaration of Helsinki and its later amendments. This study used clinical information. Before commencing the study, we explained to each patient that the data might be used for research, providing the participants with an opt-out option.

Study Population

This study reviewed the medical records of 131 consecutive patients who underwent 1-level, 2-level, 3-level, or 4-level ACDF between January 2017 and March 2021 at our institution's spine center. Inclusion criteria were as follows: (1) patients diagnosed with cervical spondylotic myelopathy, cervical spondylotic radiculopathy, cervical disc herniation, or cervical ossification of the posterior longitudinal ligament, and (2) the use of a semiconstrained rotational plate system and titanium-coated polyetheretherketone cages with iliac bone. Exclusion criteria were as follows: (1) follow-up < 1 year, (2) revision surgery performed in < 1 year, and (3) the lower-instrumented vertebra (LIV) not being visible on lateral radiographs of the cervical spine. Of the 131 patients, 119 were eligible for inclusion in this study. They were divided into 2 groups for easy analysis: short-segment (1-level or 2-level ACDF) and long-segment (3-level or 4-level ACDF) groups. The characteristics of semiconstrained rotational plate systems were expected to be more evident in the long-segment group. The short-segment group consisted of 62 patients, with a mean age and SD of 62.8 ± 14.0 years, and males accounting for 67.7%. The long-segment group consisted of 57 patients, with a mean age and SD of 63.9 ± 12.6 years, and males accounting for 64.9% (Fig. 1). Smoking status was available for 97 (25 smokers and 72 nonsmokers) of the 119 patients. Regarding comorbidities, 10, 6, and 2 patients had diabetes mellitus, cardiovascular disease, and a history of cerebrovascular disease, respectively.

Anterior Cervical Plate System Used in the Study

Two plate types were used in the study: Zevo (Medtronic), available only with variable-angle screws and a screw angle range of up to 32 degrees, and Maxan (ZimVie), available with a choice of variable- or fixed-angle screws and a screw angle range of up to 30 degrees. Of the 119 patients, Zevo was used in 69 and Maxan in 50. For Maxan, the decision to select either type of screw was made by the surgeon in the operating room. Of the 50 patients in whom Maxan was used, fixed-angle screws were used for the LIV in 24 patients.

Radiographical Analysis

Postoperative lateral radiographs of the cervical spine immediately and after 1 year in both groups were used to measure the following items. The segmental angle between the upper-instrumented vertebra (UIV) and LIV (Fig. 2) was measured to investigate how this angle changed in the postoperative course. Next, the UIV and LIV screw angles (Fig. 3) were measured to investigate changes in the positional relationship between the screws and UIV/LIV in the postoperative course. In addition, the distances from the screw base to the endplate of UIV/LIV (SBE) and from the screw tip to the endplate of UIV/LIV (STE) were measured (Fig. 4). All measurements were performed twice, and the mean values were used as representative data.

Nonunion was assessed by 2 independent blinded observers using flexion and extension radiographs at 1 year postoperatively. A diagnosis of nonunion was made when 2 observers reached a consensus on the following: (1) the measured change in interspinous distance was > 1 mm for each fusion level, and (2) the absence of bridged bone trabeculation at the cage/bone interface and between the adjacent endplates.[4,5] Revision surgery was also examined.

Statistical Analysis

Descriptive statistics were expressed as mean and SD. A 2-tailed unpaired Student t test was used to compare both groups, and statistical significance was set at $P < 0.05$. The χ^2 test was performed for nominal variables regarding the association between nonunion and comorbidities or smoking status. The kappa coefficient was calculated to assess interobserver reliability for nominal variables on nonunion. All statistical analyses were performed using IBM SPSS Statistics for Windows version 24 (IBM Corp).

RESULTS

The values obtained by subtracting the segmental angle, UIV and LIV screw angles, SBE at the UIV/LIV, and STE at the UIV/LIV immediately postoperatively from those obtained at 1 year postoperatively were summarized and statistically analyzed (Table 1). Significant differences existed between the short-segment and the long-segment groups for all items except STE at the UIV. Compared with the short-segment group, the long-segment group could not maintain the segmental angle obtained immediately postoperatively, and the screw motion within the vertebral body was larger. Particularly, the LIV screw motion in the long-segment group was more pronounced at the screw-plate interface. Figure 5 demonstrates a representative case, revealing a typical LIV screw motion and LIV deformity. For Maxan, fixed-angle screws were used for the LIV in 24 patients, and the LIV screw angle decreased by an average of 11.2 degrees at 1 year postoperatively compared with that immediately postoperatively.

Overall, 27 patients developed nonunion, with 19 (70.4%) in the long-segment group and 21 (77.8%) at the lowest fused level (Table 2). The kappa coefficient for assessing interobserver reliability of nonunion was 0.81 (95% CI, 0.68–0.95), indicating close agreement. Regarding the association between nonunion and comorbidities, nonunion was found in 2 of the 10 patients with diabetes, 2

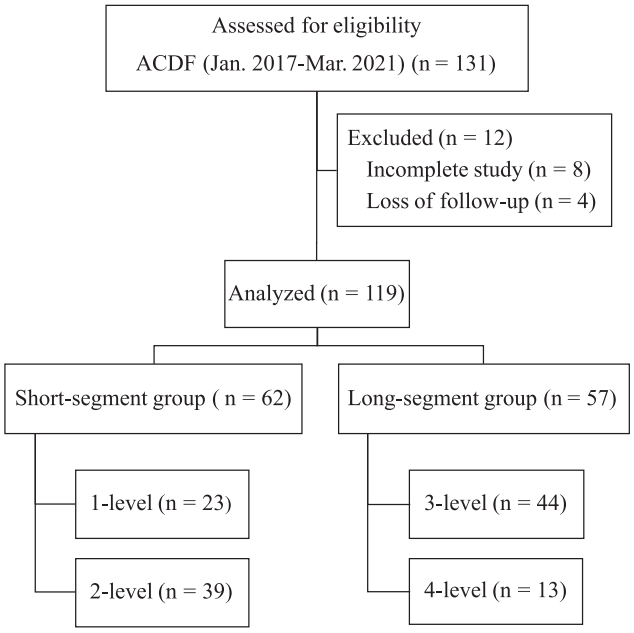

FIGURE 1. Participant flow diagram.

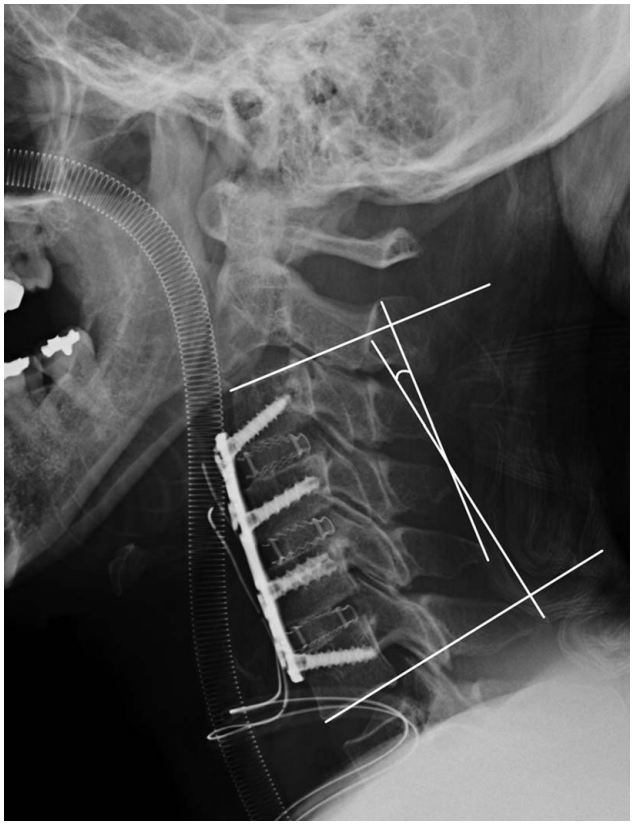

FIGURE 2. Segmental angle is between the cranial endplate of the upper-instrumented vertebra and the caudal endplate of the lower-instrumented vertebra.

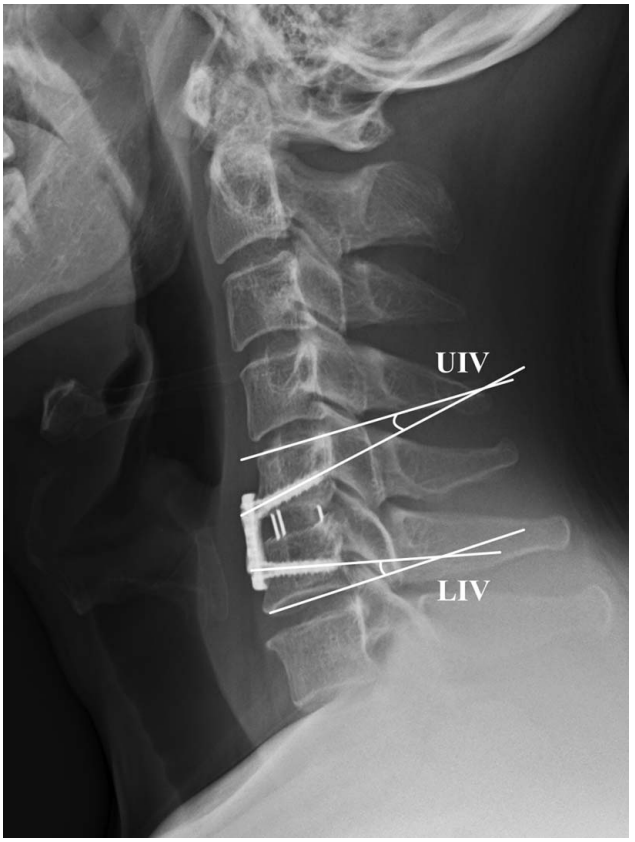

FIGURE 3. Upper instrumented vertebra (UIV) screw angle is between the cranial endplate of the vertebra and the screw trajectory. Similarly, the lower-instrumented vertebra (LIV) screw angle is between the caudal endplate of the vertebra and the screw trajectory.

of the 6 patients with cardiovascular disease, and 1 of the 2 patients with a history of cerebrovascular disease. Therefore, 5 of 18 with comorbidities and 22 of 101 without comorbidities had nonunion; the difference was not statistically significant ($P = 0.7994$). Smoking status was available for 97 of the 119 patients, with 6 of 25 smokers and 18 of 72 nonsmokers showing nonunion; the difference was not statistically significant ($P = 1.0$).

Revision surgery was required in 2 patients: 1 with 3-level ACDF 15 months after the initial surgery and 1 with 4-level ACDF 49 months after the initial surgery. The surgery was due to nonunion at the lowest fused level associated with neurological symptoms, respectively. Another patient with 4-level ACDF had screw breakage at the LIV, resulting in nonunion. However, revision surgery was not performed due to a lack of symptoms.

DISCUSSION

Ideally, semiconstrained rotational plate systems are designed to increase lordosis during the postoperative course and transfer the load to interbody cages by toggling instrumented vertebrae at the screw-plate interface without changing the positional relationship between the ver-

FIGURE 4. Line segments "a" and "b" are along the anterior wall of the vertebral body, measured as the distance from the screw base to the endplate of each instrumented vertebra (SBE), while line segments "c" and "d" are the distance from the screw tip to the endplate of each instrumented vertebra (STE).

tebra and screw. Burkhardt et al[6] reported that semiconstrained rotational plate systems outperformed semiconstrained translational plate systems in maintaining cervical lordotic correction but had a higher rate of instrumentation failure. Semiconstrained translational plate systems can distribute the load through the vertical motion of the plates. Therefore, the screws are unlikely to be loaded until the dynamization limit is reached. In rotational plate systems, screw toggling is crucial to load distribution; thus, the screws are subjected to overloading compared with the translational plate systems. Therefore, we focused on the screw motion used in semiconstrained rotational plate systems by comparing the short-segment and long-segment ACDF groups.

TABLE 1. Comparison of the Amount of Change in Each Measurement Item Immediately and 1 year Postoperatively in the Short-segment Versus Long-segment Groups

	Short-segment	Long-segment	*P*
Segmental angle (degrees)	−2.3 (5.2)	−4.7 (6.4)*	0.0234
Screw angle (degrees)			
UIV	−5.1 (6.4)	−9.1 (9.5)*	0.00778
LIV	−4.6 (6.0)	−14.5 (9.8)*	0.00000
SBE (mm)			
UIV	−0.9 (1.3)	−1.6 (1.5)*	0.00604
LIV	−1.0 (1.5)	−2.8 (1.8)*	0.00000
STE (mm)			
UIV	0.3 (0.8)	0.5 (0.9)	0.208
LIV	0.05 (1.0)	0.6 (1.6)*	0.0192

LIV indicates lower-instrumented vertebra (LIV); SBE, the distance from the screw base to the endplate of the instrumented vertebra; STE, the distance from the screw tip to the endplate of the instrumented vertebra, mean (SD); UIV, upper-instrumented vertebra.

*$P < 0.05$.

Our data revealed that at 1 year postoperatively, the short-segment and long-segment groups had lost the segmental angle acquired immediately postoperatively. However, the long-segment group had a significantly greater loss of that angle than the short-segment group. Figure 6 illustrates the single-level ACDF for simplicity and precisely illustrates our study's results. Figure 6A presents a schema immediately postoperatively. As illustrated in Figure 6B, the force should ideally be applied to the interbody cage during the postoperative course without changing the screw angle, SBE, and STE. In addition, the plate system may increase lordosis. In reality, however, as presented in Figure 6C, the screw angle changes significantly at the LIV, changing its angle in the cranial direction: STE changes only minimally, but SBE changes significantly, indicating caudal movement and possible loosening of the LIV screw. These results imply that the anterior vertebral wall of the LIV is overloaded, especially in multilevel ACDF. This overloading can cause LIV screw fracture, LIV deformation, and subsidence of the cranial endplate of the LIV, eventually causing nonunion. Rotational plate systems do not toggle the vertebrae but rather apply a vertical force to the fusion segment, as do translational plate systems.

The nonunion rate $\geq$3-level ACDF was 5.6%–53%, and thus, no consensus has been reached compared with that for 1-level or 2-level ACDF.[7–13] In our series, 77.8% of the 27 patients had nonunion at the lowest fused level. Wewel and colleagues demonstrated the incidence of radiographic pseudoarthrosis following $\geq$3-level ACDF. They described 45.8% of their patients with pseudoarthrosis, most frequently at the caudal level, but did not discuss the mechanism.[14] Our results suggest that overloading the anterior wall of the LIV contributes to the frequent nonunion occurrence at the lowest fused level in multilevel ACDF. Translational plate systems may reduce the LIV overload more than rotational plate systems, as there is more room to adjust the overall length of the construct.

Based on our study's results, regarding the surgical technique of ACDF using a plate, the screws should be inserted as close to the caudal endplate as possible and more cranially oriented for UIV, and close to the cranial endplate as possible and more caudally oriented for LIV, considering the screw migration at UIV/LIV. However, inserting the screws near the cage may increase the risk of screw breakage due to screw toggling. In this study, pol-

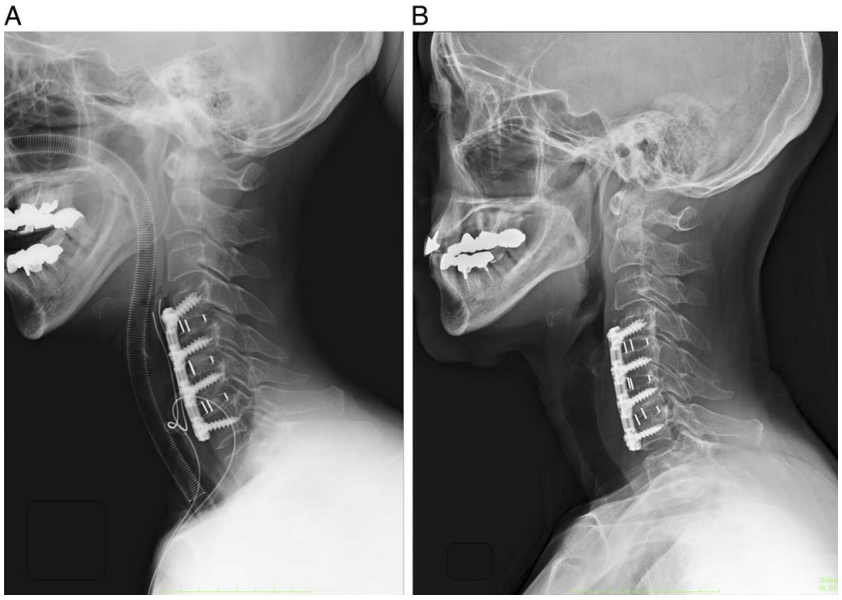

FIGURE 5. A, Immediate postoperative radiograph of 3-level anterior discectomy and fusion from C4 to C7. B, A 3-year postoperative radiograph of the same patient presents nonunion at the lowest C6/7 level and deformity of the upper endplate and anterior vertebral wall of C7. In addition, the screw angle at C7 decreased. The plate has been caudally displaced compared with the preoperative radiograph. The distance from the screw base to the endplate of C7 shortened, indicating that the screw has migrated caudally. full color online

yetheretherketone cages were used in all cases, and there were no cases of screw breakage owing to screw-cage collision. Regarding screw length, the STE result reveals a minimal difference in the postoperative course. However, this study cannot state that unicortical screws are as effective as bicortical screws.

Limitations

Two types of semiconstrained rotational plate systems were used in the study: Zevo and Maxan. Therefore, the study population was not necessarily homogeneous, as some of the cases in which Maxan was used were mixed with cases treated with variable-angle and fixed-angle screws. Although fixed-angle screws were used for the LIV in 24 patients with Maxan, the LIV screw angle decreased by an average of 11.2 degrees at 1 year postoperatively compared with that immediately postoperatively. Therefore, differences in screw type are unlikely to have significant impacts on the results of this study.

Cases with semiconstrained translational plate systems were not investigated in this study. Therefore, the screw motion obtained from this study cannot be ascertained to be characteristic only of semiconstrained rotational plate systems. Translational plate systems are theoretically unlikely to experience screw migration at UIV/LIV, as in this study. Nevertheless, it can be assumed that when the dynamization limit is reached, the LIV and LIV screws will be overloaded, as in rotational plate systems.

Although assessment of bone quality is an important component of surgery, such as ACDF aimed at achieving bone union, bone density testing was not performed preoperatively in all patients in this study. Therefore, the relationship between the results of this study and bone quality remains unclear.

Additional posterior fixation may decrease the nonunion rate of multilevel ACDF. However, the reoperation rate is low because nonunion is not always symptomatic, and it is unclear which patients are more prone to nonunion. Therefore, additional posterior fixation cannot always be recommended at initial surgery.

In conclusion, semiconstrained rotational plate systems in multilevel ACDF did not maintain the lordosis obtained immediately postoperatively during the postoperative course. These plate systems could only apply

TABLE 2. Nonunion in the Short-segment Versus Long-segment Groups

	No. levels fused	No. patients with nonunion	No. patients with nonunion at the lowest fused level
Short-segment (n = 62)	1-level (n = 23)	1	NA
	2-level (n = 39)	7	4
Long-segment (n = 57)	3-level (n = 44)	15	13
	4-level (n = 13)	4	4
Total (n = 119)		27	21

NA indicates not applicable.

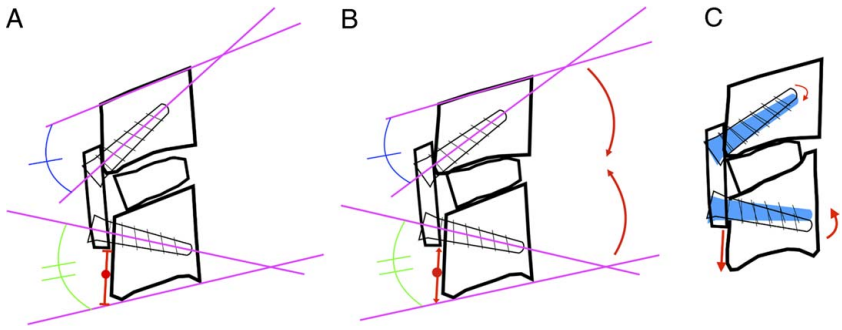

FIGURE 6. A, One-level anterior cervical discectomy and fusion with a semiconstrained rotational plate system and a cage immediately postoperatively. B, Ideal motion of the screw in the postoperative course. If the plate system can toggle the instrumented vertebrae, it can increase lordosis. C, Actual motion of the screw in the postoperative course. full color online

vertical forces to the fused segment, like translational plate systems, rather than toggling the instrumented vertebrae. In the postoperative course of multilevel ACDF, LIV screws moved within the vertebrae: the screw angle was decreased, and the SBE result revealed that the screws migrated caudally. This suggests that these plate systems have not always been effective in maintaining lordosis, and LIV screws and the anterior wall of the LIV are overloaded, resulting in a high nonunion rate at the lowest fused level.

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